THE INFLUENCE OF PSYCHOLOGICAL DISTRESS ON BASELINE CONCUSSION MEASURES

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ABSTRACT

MICHAEL JOHN BAUM: The Influence of Psychological Distress on Baseline Concussion Measures
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Accurate concussion baseline testing is necessary for appropriate post-injury comparisons to pre-injury measurements. The purpose of this study was to determine the influence of psychological distress on baseline concussion measures, and to examine the association between change in psychological distress and change in performance on clinical measures of concussion. We completed baseline testing and an assessment of psychological distress on 165 participants. Fifty-six participants completed the same procedure ten weeks later. One-way ANOVAs were used to examine differences in dependent variables at baseline between distress groups. Chi-Square tests of independence were used to examine the association between change in distress and change in clinical measures of concussion. Significant differences existed between distress groups on verbal memory, and neurobehavioral and somatic symptom reporting. Significant associations were observed between distress and postural stability, and symptom reporting. However, when considering clinical significance, psychological distress may not be a confounding variable in concussion assessment.

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To my parents Jack and Cindy: thank you for your unending support, guidance and encouragement. I owe my successes and accomplishments to you.

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CHAPTER I

INTRODUCTION

Recent events in professional and collegiate athletics have caused an increase in awareness of concussion in the media. This has resulted in increased coverage and scrutiny of the sports medicine team's management of these injuries. Approximately 1.54 million brain injuries occur each year, and 20% of those injuries occur during sports or physical activity (Sosin, Sniezek, & Thurman, 1996). For every 100,000 cases of sport-related concussion, 2.6 result in death or hospitalization. More recent data suggests that brain injuries result in about 1.1 million emergency room visits each year (Langlois, Rutland-Brown, & Wald, 2006). This increase may represent an increased awareness of concussion in the community; however, these numbers may still be an underestimation of the true number of concussions that take place over a year.

Concussions are best evaluated and managed using a multifaceted approach that includes assessment of neurocognition, postural control, symptoms, and a thorough clinical evaluation (McCrory et al., 2009). Accurate baseline testing is useful during post-injury evaluation by allowing comparison to an individualized pre-injury measurement. This comparison assists in determining a proper return to play progression. Recent consensus statements recommend baseline examination for the management of concussion. Furthermore, it is recommended that clinicians control for variables that may affect the accuracy of these measures such as effort, previous history of concussion, and learning disabilities (Aubry et al., 2002; Guskiewicz et al., 2004; McCrory et al., 2005; McCrory et al., 2009).

While 94% of institutions report conducting baseline neurocognitive exams, only 54% of those conducting these exams report checking the accuracy of their results. In general, an inaccurate baseline assessment may make it difficult to interpret post-injury assessment data (Covassin, Elbin, Stiller-Ostrowski, & Kontos, 2009). Clinicians that use compare post-injury scores to inaccurately low baseline values may prematurely return an athlete to play before they have truly recovered. Effort, a previous history of concussion, and learning disabilities can confound neurocognitive assessment (Collins et al., 1999; Green, Rohling, Lees-Haley, & Allen, 2001; Hunt, Ferrara, Miller, & Macciocchi, 2007). Beyond the realm of neurocognitive testing, postural stability can be affected by low back pain, Alzheimer's disease and Parkinson's disease (Chong, Horak, Frank, & Kaye, 1999; della Volpe et al., 2006). The baseline evaluation process is further complicated because symptoms commonly reported with concussion are not exclusive to only a diagnosis of concussion. Headaches, difficulty concentrating, and nausea may be common even without the presence of a concussion (Piland, Motl, Guskiewicz, McCrea, & Ferrara, 2006). Baseline testing procedures often attempt to control for these variables to minimize the possibility of obtaining invalid test results.

Recently, depression has been introduced as an additional confounding factor in the differential diagnosis and baseline evaluation of concussion. Links have been established between depression questionnaire scores and neurocognitive test scores, and depressive symptoms and post-concussive symptoms (Garden & Sullivan, 2010; Iverson, Brooks, & Young, 2009; Lange, Iverson, & Rose, 2010). Depression, and a history of depression, is particularly prevalent in a collegiate population with 14.9% of college students reporting a diagnosis of depression in their lifetime (Gallagher, 2010; Orr & Ketcham, 2009). Entering college may be a stressful time for some students as they face seemingly large-scale life changes. A new environment and a new social support system are among many new situations freshmen may face. Depression in college students is theorized to be due to poor adaptation and coping techniques to this new environment. The overall link between life stress and depression is widely established throughout the literature, as increased levels of psychological distress are known to be a predictor for depressive symptoms (Kelly, Roberts, & Bottonari, 2007; Lara, Klein, & Kasch, 2000; Miller & Chung, 2009). As students adapt to the collegiate setting, psychological distress decreases and depressive symptoms decrease as well (Blimling, 1981; Dyson & Renk, 2006; Fisher & Hood, 1987; Lapsley, Rice, & Shadid, 1989). Thus, the adverse psychological effects that present initially may only be apparent in the short term. After a period of acclimation to college, psychological distress and depression symptoms tend to resolve both with and without treatment (Kelly et al., 2007; Lara et al., 2000; Miller & Chung, 2009).

In the collegiate setting, concussion baseline testing is typically completed prior to an athlete's season of play, which often occurs during the early transition phase into the collegiate setting. This early transition phase is where the student-athlete is likely to experience the greatest amount of psychological distress. This increase in psychological distress and potential depressive symptoms may resolve over time as a result of coping and adaptation. Adaptation to college life may account for lower psychological distress and result in higher concussion evaluation scores relative to baseline. It is possible that completing baseline testing during this transitional time would negatively influence neurocognitive function, postural control, and symptom score. However, there is very limited literature available on psychological distress and its interaction with baseline concussion evaluation to support this claim. A recent study limited to collegiate football players and neurocognitive testing did show a relationship between psychological distress and scores at baseline, but did not evaluate any changes over time (Bailey, Samples, Broshek, Freeman, & Barth, 2010). Confounding factors such as psychological distress have significant implications on the validity of baseline neurocognitive evaluation. Comparisons back to an invalid baseline that do not accurately represent an athlete's full potential may promote clinicians to make premature, and potentially extremely dangerous, return to play decisions. A potential consequence returning to play prematurely while the athlete is still symptomatic is sustaining a second impact and developing second impact syndrome. The increased intracranial pressure resulting from this second impact causes herniation of the temporal lobes and the cerebral tonsils, brainstem compression, and potentially death (Bey & Ostick, 2009; Cantu & Gean, 2010; Wetjen, Pichelmann, & Atkinson, 2010). The purpose of this study was to determine if psychological distress influenced measures of neurocognitive function and postural control, and symptom reporting at preseason baseline. A secondary purpose was to determine whether changes in psychological distress level were associated with changes in performance on clinical measures of concussion after a ten-week adaptation period.

Variables

Independent

1. Modified Holmes and Rahe Stress Index- Revised Social Readjustment Rating Scale (SRRS-R)
    a. High psychological distress tertile group: Participants with an SRRS-R assessment score in the top 1/3 of the sample.
    b. Moderate psychological distress tertile group: Participants with an SRRS-R assessment score in the middle 1/3 of the sample
    c. Low psychological distress tertile group: Participants with an SRRS-R assessment score in the lowest 1/3 of the sample.
2. Time
    a. Baseline
    b. Post-test (10-weeks following baseline)

Dependent

1. CNS Vital Signs (CNSVS)
    a. Neurocognitive Index Standard Score
    b. Composite Memory Standard Score
    c. Verbal Memory Standard Score
    d. Visual Memory Standard Score
    e. Processing Speed Standard Score
    f. Executive Function Standard Score
    g. Psychomotor Speed Standard Score
    h. Reaction Time Standard Score

i. Complex Attention Standard Score

j. Cognitive Flexibility Standard Score

k. Reasoning Standard Score

2. Sensory Organization Test (SOT)

    a. Composite Score

3. Graded Symptom Checklist

    a. Total Symptom Severity Score by Category

        i. Somatic

        ii. Cognitive

        iii. Neurobehavioral

    b. Total Number of Symptoms Reported by Category

        i. Somatic

        ii. Cognitive

        iii. Neurobehavioral

Research Questions

1. Is there a significant difference in performance on clinical measures of concussion between participants reporting high, moderate and low levels of psychological distress?

    a. Is there a significant difference in neurocognitive performance, as measured by CNSVS, between participants reporting high, moderate and low levels of psychological distress?

        i. Neurocognitive Index Standard Score

        ii. Composite Memory Standard Score

iii. Verbal Memory Standard Score

iv. Visual Memory Standard Score

v. Processing Speed Standard Score

vi. Executive Function Standard Score

vii. Psychomotor Speed Standard Score

viii. Reaction Time Standard Score

ix. Complex Attention Standard Score

x. Cognitive Flexibility Standard Score

xi. Reasoning Standard Score

b. Is there a significant difference in postural control performance, as measured by the SOT, between participants reporting high, moderate and low levels of psychological distress?

i. Composite Score

c. Is there a significant difference in self-reported symptom severity and number as measured by the graded symptoms checklist, between participants reporting high, moderate and low levels of psychological distress?

i. Total Symptoms Reported by Category

ii. Total Symptom Severity by Category

2. Is a change in psychological distress level associated with a change in performance on clinical measures of concussion after a ten-week adaptation period?

a. Is a change in psychological distress level associated with a change in neurocognitive performance, as measured by CNSVS, after a ten-week adaptation period?

b. Is a change in psychological distress level associated with a change in postural control performance, as measured by the SOT, after a ten-week adaptation period?

c. Is a change in psychological distress level associated with a change in total symptoms reported by category and total symptom severity by category after a ten-week adaptation period?

Research Hypotheses

1. Participants reporting high levels of psychological distress will have significantly worse performances on clinical measures of concussion than athletes reporting low levels of psychological distress. Participants reporting moderate levels of psychological distress will not have significantly different performances than those in the high and low group.

    a. Participants reporting high levels of psychological distress will have significantly worse neurocognitive performances, as measured by CNSVS, than participants reporting low levels of psychological distress. Participants reporting moderate levels of psychological distress will not have significantly different performances than those in the high and low group.

    b. Participants reporting high levels of psychological distress will have significantly worse postural control performances, as measured by the

SOT, than participants reporting low levels of psychological distress. Participants reporting moderate levels of psychological distress will not have significantly different performances than those in the high and low group.

   c. Participants reporting high levels of psychological distress will have significantly higher self-reported symptom severity and frequency by category than participants reporting low levels of psychological distress. Participants reporting moderate levels of psychological distress will not have significantly different results than those in the high and low group.

2. A change in psychological distress level is associated with a change in performance on clinical measures of concussion after a ten-week adaptation period.

   a. A change in psychological distress level will be associated with a change in neurocognitive performance, as measured by CNSVS, after a ten-week adaptation period.

   b. A change in psychological distress level will be associated with a change in postural control performance, as measured by the SOT, after a ten-week adaptation period.

   c. A change in psychological distress level will be associated with a change in self-reported symptom severity and frequency by category after a ten-week adaptation period.

Operational Definitions

1. *High Psychological Distress Group:* Participants scoring in the top one-third of the sample on the SRRS-R.
2. *Moderate Psychological Distress Group:* Participants scoring in the middle one-third of the sample on the SRRS-R.
3. *Low Psychological Distress Group:* Participants scoring in the bottom one-third of the sample on the SRRS-R.
4. *Baseline testing:* Concussion testing that occurs prior to an athlete's season in order to establish an individualized "normal" value for that athlete. Typically completed within the first week of an athlete's arrival on campus.
5. *Post-test*: Repeat baseline testing to take place approximately ten weeks after baseline. This will allow time for Participants to adapt to the collegiate setting.

Assumptions

1. Participants will perform the neurocognitive assessment and SOT to the best of their ability.
2. Participants will grade symptoms truthfully and accurately.
3. Participants will answer SRRS-R scale truthfully and accurately.
4. Participants will be adapted to the collegiate setting ten weeks following baseline testing.

Limitations

1. Sample will be limited to incoming athletes at the University of North Carolina at Chapel Hill required to complete baseline testing. We will not be recruiting additional participants for our study.

2. High, moderate, and low psychological distress groups will show differences on SRRS-R however may not exhibit true pathological differences. Participants with high levels of psychological distress as measured on the SRRS-R may not be clinically diagnosed with depression.
3. The SRRS-R is a measure of life-stress that correlates well to psychological distress, however does not evaluate a participant's ability to cope with psychological distress. We will not be able to control for a participant's coping ability.

Delimitations

1. Participants will be excluded if they have been diagnosed with a concussion 6 months prior to baseline testing or if they sustain a concussion between testing sessions.
2. Participants will include incoming student-athletes at a division I institution only..

Significance of the Study

The purpose of this study was to identify how psychological distress influences baseline concussion measures in athletes. As freshmen athletes enter college they may experience difficulty adapting to college life. Poor adaptation and coping techniques can cause an increase in psychological distress and potentially lead to the development of depression. This increased distress level may result in poorer performance on baseline measures of concussion including neurocognitive scores, postural stability, and self-reported symptoms of concussion. The influence that psychological distress may have on baseline scores has significant implications on the validity of baseline concussion evaluation as a whole. Return to play decisions may be influenced by baseline scores that are not an accurate representation of athletes full potential on baseline testing. This raises the possibility that athletes are returning to play too soon based on invalid baseline scores and increasing their risk of sustaining a second impact prior to fully recovering from their first concussive injury. The consequences of a potential second impact are devastating and often result in death, thus highlighting the importance of accurate baseline measures.

CHAPTER II

REVIEW OF THE LITERATURE

Recent events in professional and collegiate athletics have caused an increase in awareness of concussion in the media. Not only has this brought scrutiny to the overall health of the athlete, but also to the sports medicine team's management of these injuries. Part of the multifaceted approach to concussion management is a baseline testing battery. Included in this baseline testing battery are neurocognitive testing, measures of postural stability, and a concussion symptom checklist. This battery of tests allows the sports medicine professional to compare an athlete's scores following a concussive injury to his or her baseline measures.

As of late, the utility of baseline concussion testing in reducing an athlete's risk for experiencing negative post-concussive outcomes has been called into question (Randolph, 2011). There have been numerous attempts in the literature to identify variables that can affect baseline concussion measures and raises the question, does baseline testing provide an accurate representation of the athlete's neurocognitive and postural control capabilities? If our baseline measures are invalid, we cannot safely compare post-injury scores to baseline and use the results to aid in a return to play decision.

The purpose of this review is to identify factors affecting baseline concussion measures. Furthermore, we will discuss available literature on the effect that psychological distress may have on baseline concussion measures, including neurocognitive testing, postural stability, and concussion symptom scores.

Epidemiology

In the United States alone, traumatic brain injuries yield 1.1 million emergency room visits each year resulting in 235,000 hospitalizations and 50,000 deaths (Langlois et al., 2006). Of all brain injuries, approximately 20%, or 300,000 were due to sports/physical activity (Sosin et al., 1996). The consequences of sport related mild traumatic brain injury (TBI) could be particularly devastating. For every 100,000 cases of sport related mild TBI 2.6 will result in death or hospitalization ("Sports-related recurrent brain injuries--United States," 1997). It is likely that this number has increased as a result of increased attention to the recognition, diagnosis and management of mild TBI. The recognition of concussion as a serious injury may also contribute to the inflation of this statistic, but still may underrepresent the true number of injuries taking place.

The cost of concussion has been evaluated throughout the literature. A systematic review conducted within the past ten years concluded that the cost of concussion is high, citing one study as finding the cost at $12.5 billion in 1982. Findings suggest that most of the cost of concussion is associated with indirect expenses such as time lost from work and loss of productivity (Borg et al., 2004). Again, this statistic has likely increased with increased recognition and diagnosis of mild TBI, but still may be an underrepresentation of the true cost of concussion on the health care system.

The increased recognition of concussion in the media likely results from coverage of high profile sports such as football. The relatively high incidence of concussion in football further contributes to increased media attention (Dick et al., 2007). Concussion makes up approximately 6.8% of injuries in fall games and 5.5% of injuries in fall practices in collegiate football (Dick et al., 2007). Overall, NCAA injury surveillance suggests that mild TBI accounts for 6% of all football injuries. Concussions, however, are not exclusive to football. NCAA injury surveillance has also found that concussion accounts for 18.3% of injuries in women's ice hockey, 7.9% of injuries in men's ice hockey, and 6.3% of injuries in women's lacrosse (Hootman, Dick, & Agel, 2007).

These incidence rates and resulting increased public interest and media attention have created a response within the medical community. A shift in focus towards evaluation and management of mild TBI is apparent in the literature. Specifically, a multifaceted approach is suggested for concussion evaluation including neurocognitive function, postural control, a symptom checklist, and clinical evaluation (McCrory et al., 2009). In addition, a plethora of research exists that attempts to standardize concussion management (Aubry et al., 2002; Guskiewicz et al., 2006; Guskiewicz et al., 2004; McCrory et al., 2005).

Baseline Evaluation

A multifaceted concussion evaluation consists of neurocognitive testing, postural control, a symptom checklist, and clinical evaluation. Baseline testing of these measures has been recommended to establish each individual athlete's "normal" pre-injury scores (Guskiewicz et al., 2004). These baseline tests allow for an individualized comparison if an athlete is to sustain a concussion. A comprehensive concussion history is also suggested to be included within baseline testing. This includes not only the number of previous concussions, but also examines other head, neck, and/or facial injuries (McCrory et al., 2005).

Neurocognitive Evaluation

Barth at the University of Virginia pioneered the concept of neurocognitive evaluation. The UVA Prospective Study of Mild Head Injury in Football examined 2350 athletes across ten universities. By examining baseline measures of neurocognitive function compared to post-injury data, it was found that concussion caused a measurable deficit in cognitive processing. Furthermore, recovery trends were established that showed recovery occurred between five and ten days post injury (Barth et al., 1989). More specifically, cognitive deficits have been observed in subjects 24 and 48 hours following a concussion (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Lovell & Collins, 1998). These deficits have tend to decrease largely by five days post-injury and are fully resolved by ten days post-injury (Iverson, Brooks, Collins, & Lovell, 2006). However, in order for post-injury data to have meaningful significance, it is recommended that baseline testing take place for neurocognitive measures.

Concussion consensus statements released within the past ten years also suggest that baseline neurocognitive evaluation is necessary for athletes at risk for sustaining a concussion (Aubry et al., 2002; Guskiewicz et al., 2004; McCrory et al., 2005). In addition, neurocognitive evaluation cannot be used as a standalone measurement to quantify concussion or make a return to play decision. This evaluative technique must be paired with other means of assessment, including but not limited to postural stability, symptom checklists, and clinical examination (Grindel, Lovell, & Collins, 2001). As of late, the NCAA has followed suit in recommending baseline testing. In April of 2010 the NCAA mandated that baseline testing is required for high-risk sports including football, basketball, baseball, ice hockey, soccer, and others (Runkle, 2010).

Based on these recommendations, many academic institutions in the United States have utilized neurocognitive testing in concussion evaluation and management. Approximately 94% of institutions with access to neurocognitive testing utilize it in baseline assessments of their athletes. Interestingly, only 55% of those institutions report checking the accuracy of their exams (Covassin et al., 2009).

Postural Stability

Postural stability has been well established as a method of evaluating athletes following a concussive injury utilizing both high technology and low technology measures (Guskiewicz, 2011). A significant decrease in postural stability has been found in athletes one day following a concussion. Furthermore, measures that specifically evaluate the three main sensory systems, visual, vestibular, and somatosensory, have suggested that there are significant sensory interaction problems following a head injury (Guskiewicz, Riemann, Perrin, & Nashner, 1997). In addition to decreased postural stability one day following injury, a deficit in postural stability has been observed up to five days following injury. Despite this decrease, recovery in postural stability does occur between days one and three (Guskiewicz, Ross, & Marshall, 2001). As with neurocognitive testing, postural stability measures are not to be used as a stand alone method of evaluating concussed patients (Broglio, Ferrara, Sopiarz, & Kelly, 2008). Self reported symptom scores and a clinical exam are also needed to obtain a complete picture of the concussed athlete.

Graded Symptom Checklist

The third piece to a multifaceted approach to concussive evaluation and management involves a self-reported graded symptom checklist. A self-reported symptom inventory was created to aid in quantifying an athletes concussive symptoms (Lovell & Collins, 1998). This original graded symptom checklist includes 21 symptoms on a Likert scale from 0-6 where a higher score correlates to more symptoms. This scale is subjective, however it is commonly used in sport concussion studies throughout the literature. Using this scale or slightly modified versions, it has been observed that most concussive symptoms resolve between five and seven days with the average duration of symptoms being 3.5 days (Guskiewicz et al., 2003; McCrea et al., 2003). The validity of the graded symptom checklist has been established, however it is possible for healthy subjects to report concussive symptoms at baseline due to confounding factors (Piland et al., 2006). Self-reported symptoms may be divided into categories of somatic, cognitive, and neurobehavioral symptoms (Piland et al., 2006).

Summary

A multifaceted concussion assessment consists of neurocognitive testing, postural control, a symptom checklist, and a clinical evaluation. Correct interpretation of these scores at baseline or following injury becomes challenging if the original baseline measurements are not accurate and valid. Clinically, the significance of invalid baseline concussion measures may be devastating. Second Impact Syndrome, or the risk of sustaining a second impact while still symptomatic from a concussive injury has been documented throughout the literature (Bey & Ostick, 2009; Wetjen et al., 2010). It is generally accepted that this second concussive impact prior to resolution of the first concussion causes a loss of autoregulation of cerebral vasculature. This leads to brain swelling within the cranium, and an increase in intracranial pressure. The increase in intracranial pressure results in herniation of both the temporal lobes and the cerebral tonsils, and brainstem compression. Brain stem failure occurs rapidly following impact with respiratory failure taking place between two to five minutes following impact. Numerous case studies have also been presented documenting this cascade of events (Cantu & Gean, 2010). The consequences of returning to play prematurely clearly speak to the need for accurate baseline testing.

Confounding Factors in Concussion Evaluation

Neurocognitive Evaluation

A variety of factors have been identified as potential confounding variables in neurocognitive testing. Poor effort has been seen to result in decreased scores on neurocognitive measures (Green et al., 2001). Specific deficits have been noted in the areas of information processing, memory, attention/concentration, learning, and gross motor speed as a result of poor effort. The influence of effort on the outcome of neurocognitive evaluation has led authors to recommend the inclusion of an effort assessment to increase the validity of these measures (Hunt et al., 2007).

In addition to effort, a previous history of concussion has been established as causing decreased neurocognitive scores. A history of two or more concussions has been shown to result in decreased executive function and speed of information processing (Collins et al., 1999). Similarly, a history of learning disability has been established as causing a decrease in neurocognitive scores. Specific deficits have been measured in executive functioning, speed of information processing, and speeded word fluency (Collins et al., 1999).

Postural Stability

There is not a great deal of literature surrounding potential confounding factors in measures of postural stability, specifically in regards to computerized assessments of postural stability. However, factors that may be common in an athletic population have been shown to cause a decrease in postural stability. For example, low back pain has been shown to cause a decrease in measures of postural stability (della Volpe et al., 2006). Although the literature in this topic examined chronic low back pain in a non-athletic population, it is reasonable to assume that athletes experiencing low back pain may also show decreased measures of postural stability. Other pathologies common to the athletic population have been examined in terms of postural stability. Interestingly, postural stability does not seem to be significantly different in patients with a reconstructed anterior cruciate ligament compared to controls (Henriksson, Ledin, & Good, 2001; Mattacola et al., 2002). On the other hand, chronic ankle instability has been described to negatively influence postural stability (Gribble, Hertel, Denegar, & Buckley, 2004). Moving away from the athletic population, decreased measures of postural stability have also been observed in patients suffering from Alzheimer's and Parkinson's disease (Chong et al., 1999). Despite the fact that these pathologies are less common in an athletic population, the literature does speak to the sensitivity of postural stability measures to certain pathologic conditions. The ability of postural stability tests to detect subtle, however significant, differences in subjects with these pathologies raises the question, can we find differences in patients with other pathologies? It is possible that postural control measures may also be sensitive to differences in patients with and without depressive symptoms resulting from psychological distress?

Graded Symptom Checklist

Concussion symptom checklists may be affected by a variety of factors, not only concussion. Healthy subjects may report concussive symptoms at baseline measurement such as headache, difficulty concentrating, and drowsiness. However, these symptoms are not exclusive to those suffering from a concussion (Piland et al., 2006). Hydration status also plays a role in concussion symptom reporting. Relative to a control group, acutely dehydrated subjects have been observed to report an increase in concussive symptoms and an increase in the severity of concussion symptoms (Patel, Mihalik, Notebaert, Guskiewicz, & Prentice, 2007). A history of concussion has also been established as a variable affecting symptom reporting. A history of two or more concussions results in an increase in symptom reporting relative to subjects who have not sustained a concussion (Collins et al., 1999).

Depression as a Confounding Factor in Concussion Evaluation and Management

Depression has recently been introduced as a confounding factor in the differential diagnosis, evaluation, and baseline testing of concussion. When comparing depression questionnaire scores to the results of neurocognitive tests, high depression scale scores have a significant moderate to large effect on neurocognitive test results (Iverson et al., 2009). Similarly, symptoms of depression and post-concussive symptoms have also been linked. Subjects with no history of concussion who score high on depression scales also report more post-concussive symptoms (Garden & Sullivan, 2010; Lange et al., 2010). Depression alone has been observed to have a significant impact on post-concussive symptom reporting. Furthermore, subjects who suffer from both depression and a mild TBI tend to report more symptoms than subjects with only mild

TBI (Garden & Sullivan, 2010; Lange et al., 2010). The similar symptoms of concussion and depression can potentially create problems in differentially diagnosing these conditions. This is especially true in an athlete with depression who is suspected of sustaining a concussion.

A body of literature also exists that links the neural mechanisms of depression to concussion. Symptoms common of mild TBI correlate to neural responses associated with major depression (Chen, Johnston, Petrides, & Ptito, 2008). In addition to neural responses, brain activity at specific anatomical landmarks has also been studied, most recently in veterans suffering from blast related mild TBI. Veterans who suffer from blast related mild TBI show increased activity in portions of the brain responsible for emotional regulation. This increased activity has resulted in averse emotional processing in these patients (Matthews et al., 2010). The similar presentation of concussion and depression not only makes differential diagnosis difficult, but may also affect baseline concussion assessment.

The effect of recurrent head injuries on a variety of outcome measures has been studied throughout the literature. Recurrent head injuries have been associated with increased risk of developing major depression. Retired National Football League players sustaining multiple head injuries show an increased prevalence of clinically diagnosed depression later in life (Guskiewicz et al., 2007). It has also been established that those suffering from depression score poorer on tests of neurocognitive function than healthy subjects. Specific neurocognitive deficits can be identified in depressed subjects when compared to a control. In one study, significant deficits were observed in all five domains measured including memory, psychomotor speed, reaction time, complex attention and cognitive flexibility (Iverson et al., 2009).

In total, the literature suggests that concussion and depression are closely intertwined and often present in a similar manner. This relationship and similarity to concussive symptoms not only makes differential diagnosis difficult, but may also influence baseline concussion assessment. These potential confounding factors have significant implications on the validity of baseline concussion evaluation. Return to play decisions may be influenced by baseline scores that are too low and not an accurate representation of athletes full potential on these assessments. Although links have been established between concussion and depression, depression has not been extensively explored as a potential confounding factor in baseline concussion assessment.

Depression in the College Population

Depression is commonly reported as an extremely prevalent condition in the adolescent and young adult population, specifically among those attending college. In a survey of directors of college/university counseling centers, 91% report a trend of increasing number of students with severe psychological problems (Gallagher, 2010). While this does not speak only to depression, other studies have found depression alone to be a significant problem among college students with 14.9% of students reporting having a diagnosis of depression in their lifetime. Of those reporting a diagnosis of depression, 32% of diagnoses occurred within the past school year (Orr & Ketcham, 2009).

There are conflicting reports regarding the incidence of depression among athletes compared to the general college population. Two schools of thought exist as to why athletes may or may not have increased incidence of depression. Athletic participation in and of itself may decrease the risk of depression due to the health benefits of athletic participation and the stress relief involved with participation. On the other hand, the pressure to perform well may increase the risk of depression (Proctor & Lenzo-Boan, 2010). The same authors also concluded that it is likely that an athletic population may under-report depressive symptoms.

Psychological Distress as a Predictor of Depressive Symptoms

There are many proposed explanations for the increased prevalence of depression in a collegiate population including poor adaptation and poor coping techniques. Unfamiliarity with college and high expectations from parents and the student him/herself presents a great challenge to these students. This challenge often results in difficulty adapting to the new situation (Blimling, 1981; Lapsley et al., 1989). This "college change" stress is also a predictor of depressive symptoms (Dyson & Renk, 2006). Other forms of stress, such as major life events including moving to college, have adverse psychological effects in the short term. Major life events can also result in increased psychological disturbance, particularly depression (Fisher & Hood, 1987). The overall link between life-stress, psychological distress and depression has been established and widely reported throughout the literature. It has also been widely accepted that psychological distress is a predictor for depressive symptoms (Mazure, 1998; Monroe, Slavich, & Georgiades, 2009).

As college students begin to adapt to their new environment, depressive symptoms may decrease. These adverse psychological effects resulting from life change stress may only be apparent in the short term and dissipate following a student's adaptation to college (Fisher & Hood, 1987; Lapsley et al., 1989). It is important to note that the majority of concussion baseline testing takes place during this short term and prior to any adaptation that may take place. Interestingly, the observed decrease in symptoms is possible both with and without treatment for depression (Kelly et al., 2007; Lara et al., 2000; Miller & Chung, 2009).

Methodological Considerations

Neurocognitive Testing

CNS Vital Signs is a computerized neurocognitive assessment that uses a battery of eight widely used and reliable neurocognitive tests. Using this battery, CNSVS has been shown to be sensitive to both the severity and degree of recovery of brain injuries and is able to differentiate between healthy subjects and those suffering from a moderate concussion and those suffering from a severe concussion (Gualtieri & Johnson, 2008). This makes CNSVS a prime tool in the evaluation of sport concussion. Furthermore, CNSVS has been observed to correlate well to both conventional and computerized versions of neurocognitive tests. Test-retest reliability and discriminate validity has also been established and is comparable to similar, and more traditional, tests of neurocognitive function. Normative data has also been established for CNSVS using a sample of 1069 subjects between the age of 7 and 90 (Gualtieri & Johnson, 2006, 2008). Specifically regarding depression, neurocognitive deficits have been demonstrated in subjects with depression using the CNSVS system (Iverson et al., 2009).

Postural Stability Assessment

The Sensory Organization Test (SOT) is a computerized measure of postural stability that utilizes two force plates on a moveable surface and a moveable visual surrounding to measure a subject's center of pressure during six varying conditions. In conditions one and two both the surface and visual surrounding are stable, however eyes are closed in condition two. Condition three involves a moving visual surrounding with the eyes open. Under condition four the surface is moving while the visual surrounding is stationary with the eyes open. Condition five involves a moving surface with the subject's eyes closed. Condition six involves movement of both the surface and visual surrounding with the subject's eyes open.

Using these six conditions, contributions from the body's three main sensory systems: visual, vestibular, and somatosensory, can be calculated in addition to a composite score. The interaction of these systems and their contribution to overall postural stability may also be assessed. Specifically, decreases in postural stability have been observed following concussion using the SOT. Significant declines in postural stability have been observed one day following injury, with recovery taking place within the first three days. Typically, baseline postural stability measures are obtained between the third and fifth day post injury. (Guskiewicz et al., 1997; Guskiewicz et al., 2001). The SOT has been utilized throughout the literature in sport concussion studies, but also in studies evaluating low back pain, and studies examining Alzheimer's and Parkinson's disease in a geriatric population. The SOT has shown decreases in postural stability in patients suffering from low back pain, Alzheimer's and Parkinson's disease (Chong et al., 1999; della Volpe et al., 2006; Guskiewicz et al., 1997; Guskiewicz et al., 2001; Patel et al., 2007). The specificity of the SOT in detecting change in one or more variable has been established at 57% while the sensitivity has been established at 80%. In both cases a 75% confidence interval was used (Broglio et al., 2008).

Symptom Reporting

The graded symptom checklist (GSC) was first established to aid in the assessment of concussed collegiate football players. Our GSC uses a 18 item self report checklist that examines symptoms common to concussion on Likert scale ranging from 0 to 6. This yields a total possible score of 108. Using this scale, a higher total score relates to a greater number of reported and/or more severe symptoms (Lovell & Collins, 1998). The validity of the GSC has been established however it is possible for healthy subjects to report many of the symptoms in the absence of concussive injury, as some symptoms are not exclusive to just concussion (Piland et al., 2006). The GSC has also been used throughout the sport concussion literature in quantifying symptoms both before and after a concussive injury (Guskiewicz et al., 2003; Lovell & Collins, 1998; McCrea et al., 2003; Patel et al., 2007).

Stress Scales

The Revised Social Readjustment Rating Scale (SRRS-R) was devised in 1998 in response to many criticisms of the original Holmes and Rahe Stress Index (Holmes & Rahe, 1967). Criticisms of the original scale that were addressed in the revision include: the size and composition of the original sample used by Holmes and Rahe to calculate weights for the original 43 items of the scale, overlapping of life events and symptoms of stress and depression, ambiguity and bias in some items, subjectivity and variability of an individuals perception of stress, and the accuracy of the weighting of each item (Hobson et al., 1998; Monroe et al., 2009). Despite these criticisms, the SRRS is an extremely popular and widely used measure throughout the literature. The original form of the

SRRS has been cited over 4000 times since its development in 1967 (Hobson et al., 1998).

The SRRS-R is used as a measure of life stress to predict the probability that a subject will develop an illness, including depression (Rahe, Mahan, & Arthur, 1970). Again, the overall link between life-stress, psychological distress and depression has been established and widely reported throughout the literature. It has also been widely accepted that psychological distress is a predictor for depressive symptoms (Mazure, 1998; Monroe et al., 2009).

Subjects complete the scale by rating the frequency that each of the 51 items has happened to them in the past 12 months. These scores are multiplied by the weighted “stressfulness” of each item and summed for all items to give a total score. Scores below 150 correlate to low stress, scores between 150-299 correlate to moderate stress, and scores above 300 correlate to high stress (Hobson & Delunas, 2001; Hobson et al., 1998).

Alternative stress measures were considered prior to selecting the SRRS-R. Our other options included the Zung Self-rating Depression Scale and the Personality Assessment Index. The Zung scale is a 20 item self-report scale that attempts to quantify depression. Subjects are asked to rate the frequency that they experience depressive symptoms on a Likert scale from zero to four. Although the scale is very popular, widely used throughout the literature, and correlated to Hamilton Rating Scale, Minnesota Multiphasic personality inventory, and a physicians global rating of depression; we were concerned that the scale was overly simple and would not be sensitive enough to detect subtle changes in depression and stress that we were hoping to measure (Biggs, Wylie, & Ziegler, 1978; Zung, 1965; Zung, Richards, & Short, 1965).

The Personality Assessment Inventory was also examined to address concerns of finding a test sensitive enough to detect subtle changes in distress or depression level. Relative to the Zung scale, the Personality Assessment Index is much more complex and consists of over 22 subscales. Subscales are derived from 344 items where subjects are asked to rate the frequency of feelings, thoughts, and symptoms on a four point Likert scale. The test has been used throughout the literature, specifically in subjects suffering from traumatic brain injuries, and is sensitive enough to capture slight changes in depression or distress level (Demakis et al., 2007; Smith, Gorske, Wiggins, & Little, 2010; Till, Christensen, & Green, 2009). However, due to the complexity of the exam and its length, over 45 minutes to complete, we decided to avoid using this index.

Rationale for Study

Neurocognitive testing, postural stability assessment, and a graded symptom checklist are all important aspects in the proper management of concussion. Baseline scores for these measures are key in the clinical management following a concussion. However, these baseline measurements may be confounded by a number of factors including effort, previous history of concussion, and learning disabilities. Depression has recently been introduced as a potential confounding variable in the baseline testing of athletes. The link between concussion and depression has been established, as well as the link between life stress and depression.

Despite these links in the literature, few studies have examined the effect of depression or psychological distress on baseline testing measures such as neurocognitive testing, postural stability, and a symptom checklist. To our knowledge, only one study has examined the effect of psychological distress on baseline concussion testing (Bailey et al., 2010). Although the authors did conclude that a significant and meaningful relationship exists between psychological distress and baseline concussion testing, several aspects of this study must be examined. The sample for this study only included collegiate male football players and did not examine any females or any sport other than football. The baseline concussion measurement in this study was a computerized neurocognitive test that only yielded indices of simple reaction time, complex reaction time, and processing speed. There were no measures of postural stability, and no symptom checklist scores. Regarding the measure of psychological distress, this measure was not included in the baseline concussion assessment but was instead part of a separate academic screening. Subjects were selected retrospectively if they had completed both the concussion and academic screening. The two screenings did not take place at the same time, however were obtained "typically" within one week of each other. Finally, this study did not retest subjects who scored "high" on psychological distress at a later time to account for adaptation. To our knowledge there is no literature available that evaluates psychological distress and baseline concussion measures over time.

Confounding factors have significant implications on the validity of baseline concussion evaluation. Return to play decisions may be influenced by baseline scores that are too low and not an accurate representation of an athletes full potential on these measures. A high prevalence of depression in a collegiate population and the link between psychological distress and depression warrants the examination of psychological distress and its effects on baseline concussion evaluation. Also, college students have the potential to show a decrease in depressive symptoms as they adapt to college life. This has the potential to invalidate their baseline concussion exam scores and may also influence the clinician's decision on when baseline testing should take place. No previous studies have examined how changes in psychological distress following adaptation to college influences clinical measures of concussion.

CHAPTER III

METHODOLOGY

Participants

A convenience sample of 165 incoming freshman and transfer student-athletes at the University of North Carolina at Chapel Hill completed baseline concussion testing. Of the 165 participants who completed baseline testing, 123 met our inclusion and exclusion criteria. All participants were part of a larger ongoing clinical concussion management program. All participants signed an informed consent form approved by the Office of Human Research Ethics at The University of North Carolina at Chapel Hill. Athletes required to complete baseline concussion testing included athletes from baseball, men's and women's basketball, men's junior varsity basketball, junior varsity and varsity cheerleading, field hockey, football, gymnastics, men's and women's lacrosse, men's and women's soccer, platform diving, softball, pole vault, wresting, and any other varsity athletes who may need baseline testing per orders from the team physician. Participants were excluded if they enrolled in the spring prior to the fall of their freshman year, had a history of concussion within six months of baseline testing, sustained a concussion between baseline and post-testing, or scored less than 10% on the neurocognitive index domain percentile.

Measurements and Instrumentation

Holmes and Rahe Stress Index- Revised Social Readjustment Rating Scale (SRRS-R)

The Revised Social Readjustment Rating Scale (SRRS-R) is a self reported measure of life-stress that has been used to predict the probability that a participant will develop a variety of illnesses, including depression (Rahe et al., 1970). Life-stress has been linked throughout the literature to our variable of interest, psychological distress(Mazure, 1998; Monroe et al., 2009). The scale consisted of 51 items of weighted life events. To complete the test, participants were asked to rate the frequency that each of the 51 items has happened to them in the past 12 months. The most commonly reported items, derived from normative value testing, may be categorized in five themes: (1) death and dying, (2) healthcare issues, (3) crime and the criminal justice system, (4) financial/economic, and (5) family related. Frequency scores were multiplied by weighted "stressfulness" of each item and summed for all items to give a total score. Scores below 150 indicate low stress, scores between 150-299 indicate moderate stress, and scores above 300 indicate high stress (Hobson & Delunas, 2001; Hobson et al., 1998). Despite many criticisms, the original SRRS has been widely accepted and used throughout the literature with over 4000 citations since its development in 1968 (Hobson et al., 1998; Holmes & Rahe, 1967). Criticisms of the original scale that were addressed in this revision include: the size and composition of the original sample used by Holmes and Rahe to calculate weights for the original 43 items of the scale, overlapping of life events and symptoms of stress and depression, ambiguity and bias in some items, subjectivity and variability of an individuals perception of stress, and the accuracy of the weighting of each item (Hobson et al., 1998; Monroe et al., 2009).

For the purpose of our study, we modified the SRRS-R by removing eight items that healthy college aged athletes are unlikely to experience (Appendix A). These items included: (1) foreclosure on a loan/mortgage, (2) divorce, (3) adult child moving in with parent/parent moving in with adult child, (4) child develops behavior or learning problem, (5) failure to obtain/qualify for mortgage, (6) child leaving home, (7) obtaining a home mortgage, and (8) retirement. The language of the items was also altered to be more specific to our target population. Finally, our targeted time frame included only the previous four weeks to capture acute psychological distress. Our SRRS-R and overall testing protocol was pilot tested for feasibility of instrumentation on a group of athletes returning for re-baseline testing prior to the start of a non-traditional training season.

CNS Vital Signs (CNSVS)

CNS Vital Signs is a computerized neurocognitive assessment that generated eleven clinical domain scores from eight separate neurocognitive tests. These neurocognitive tests include:

(1) <u>Verbal Memory Test:</u> Participants were shown 15 words and asked to remember them. A longer list of 30 words containing the original 15 words randomized among 15 distracter words was then displayed and participants were asked to recognize the original 15 words. The test was repeated again at the end of the testing battery to examine delay recognition of the word list. Scores were calculated by taking the correct amount of hits and passes, both delayed and immediate.

(2) <u>Visual Memory Test</u>: Similar to the verbal memory test, participants were instead shown 15 geometric shapes and asked to remember them. A longer list of

30 shapes containing the original 15 shapes randomized among 15 distracter shapes were then displayed and participants were asked to recognize the original 15 shapes. The test was repeated again at the end of the testing battery to examine delay recognition of the shapes. Scores were calculated by taking the correct amount of hits and passes, both delayed and immediate.

(3) Finger Tapping Test: Participants completed three trials on each hand where they were asked to press the space bar as many times as possible with their index finger within a ten second time frame. Scores were calculated by taking the average number of taps for each hand.

(4) Symbol Digit Coding: Participants were presented with a key of eight randomly selected symbols and matched to digits one through eight. Participants were then presented with a similar key, but with missing digits. Participants were instructed correctly match symbols to the digit designated by the key at the top of the screen. Scores were calculated by summing the correct responses completed in two minutes.

(5) Stroop Test: The Stroop test consisted of three separate tests. The first test measured simple reaction time. Participants were asked to press the space bar as soon as any word appears on the screen. The words red, yellow, blue, and green in black font appear in random order. In the second test, the same words were presented in color. Participants were to press the space bar when the font color matches the word. Finally, the third test required participants to press the space bar when the font color did not match the word. Reaction time scores from these tests yielded a measure of information processing speed.

(6) Shifting Attention Test: This measured a participant's ability to change from one set of instructions to another both quickly and accurately. Participants were asked to match objects by either shape or color, however the rules for matching changed randomly throughout the test. For any given rule, the subject was asked to match a shape on the top of the screen to one of two shapes on the bottom of the screen. Scores from this test included the number correct, errors, and response time (ms).

(7) Continuous Performance Test: The Continuous Performance Test measured the ability of a subject to maintain focus and attention over time. The subject was simply asked to press the space bar every time the letter "B" appears on the screen among distracter letters. The test was scored by adding correct responses, commission errors, and omission errors.

(8) Non-verbal Reasoning Test: 15 puzzles were presented to the subject in increasing degree of difficulty. The participant was asked to correctly identify a missing element or variable that completes a pattern. The test was scored using the number of correct responses and the participant's reaction time.

Eleven clinical domains were calculated from the results of these neurocognitive tests. We chose to utilize standard scores for all domains in our statistical analyses. The CNS Vital Signs has been correlated well to both conventional and computerized versions of neurocognitive tests. Also, test-retest reliability and discriminate validity has been established and is comparable to similar, and more traditional, tests of neurocognitive function. Normative data has also been collected in 1069 participants ranging in age from 7 to 90 years old (Gualtieri & Johnson, 2006, 2008). Appendix B contains an overview of CNS Vital Signs test modules, cognitive domains evaluated, and a description of the test module.

Sensory Organization Test (SOT)

The Sensory Organization Test is a computerized assessment of postural stability that utilized measurements of a participant's center of pressure to measure center of gravity sway. The testing protocol consisted of six conditions. Each condition was repeated three times, resulting in 18 total trials throughout the testing battery. Each trial is 20 seconds long. The six conditions included:

(1) Condition 1: Stable base of support with fixed visual field (eyes open).

(2) Condition 2: Stable base of support with fixed visual field (eyes closed).

(3) Condition 3: Stable base of support with sway referenced movement of the visual field (eyes open).

(4) Condition 4: Sway referenced support surface with fixed visual field (eyes open).

(5) Condition 5: Sway referenced support surface with fixed visual field (eyes closed).

(6) Condition 6: Sway referenced support surface with sway referenced movement of the visual field (eyes open).

Measurements under these conditions allowed for an evaluation of the sensory, vestibular, and somatosensory system's contribution to postural stability. A composite equilibrium, somatic ratio, visual ratio, vestibular ratio, and visual preference ratio scores were generated from the six conditions to aid in the evaluation of the body's systems that contribute to postural stability. For the purposes of our study, we chose to use only the composite score. Appendix C contains and overview of the SOT conditions.

The sensitivity and specificity of the SOT has been established at 80% and 57% respectively using a 75% confidence interval (Broglio et al., 2008). The SOT has been widely used in the sports medicine literature, as well as balance research (Guskiewicz et al., 1997; Guskiewicz et al., 2001; Patel et al., 2007).

Graded Symptom Checklist (GSC)

Graded symptom checklists have been used throughout the literature as means of quantifying a patient's symptoms following a concussion (Guskiewicz et al., 2003; Lovell & Collins, 1998; McCrea et al., 2003; Patel et al., 2007). The validity of a graded symptom checklist has been established. Symptoms such as headache, difficulty concentrating, drowsiness, and others are not exclusive to concussion (Piland et al., 2006).

We used an 18-item graded symptom checklist built in the CNSVS software (Appendix D). Participants ranked each symptom using a seven-point Likert scale from 0 to 6 (0: not experiencing, 1-2:mild, 3-4:moderate, 5-6: severe). Since the purpose of the graded symptoms checklist is to determine how a participant feels on a regular basis, participants were told to grade their symptoms only if they experience them more than three times per week. Higher scores were interpreted to mean more symptoms, or more severe symptoms. For the purposes of our study we utilized the total symptoms reported by category, and total symptom severity by category (Table 3.1) in our statistical analysis. A complete overview of all clinical measures of concussion may be found in Appendix E.

Procedures

Participants reported to the Matthew Gfeller Sport-Related Traumatic Brain Injury Research Center in groups no larger than six for baseline concussion testing prior to the start of their sport season. Upon arrival participants signed an informed consent form approved by the Office of Human Research Ethics at The University of North Carolina at Chapel Hill and also indicated whether they would be interested in retesting after ten weeks. Each participant completed a predetermined specific test order that was outlined and recorded in his or her testing folder. This ensured that proper counterbalancing took place between participants. Baseline testing consisted of CNSVS, SOT, GSC, and SRRS-R. The GSC and SRRS-R were built into the CNSVS software and completed in a room with four computers separated by dividers. The GSC was completed prior the to the CNSVS test battery and the SRRS-R was completed following the test battery. Distractions were be minimized as much as possible by limiting noise. Participants were not allowed to communicate with each other or use their cell phones during testing. A trained technician administered the neurocognitive testing. The SOT was conducted in a separate room and operated by a technician trained in operating the equipment. In total, testing took approximately an hour and fifteen minutes for each participant to complete.

Following testing, participants were divided into high, moderate or low psychological distress tertiles based on their SRRS-R scores. Participants were blinded to their groupings. All participants indicating an interest in returning for post-testing were invited to return ten weeks following their original baseline. Participants were contacted via email addresses they provided at baseline when indicating interest in returning. Based on available literature demonstrating that a 10-week period of time is needed for individuals to adapt to new social settings, we completed our post-testing ten weeks following baseline testing (Lapsley et al., 1989). Due to likely scheduling conflicts with participants, we used a testing window of ten weeks ± 3 days from original baseline. We also attempted to keep the time of day consistent within ± 2 hours of original baseline. Ten weeks was chosen because major life events have been found to have adverse psychological effects in the short term, but adaptations have been observed after a six week period (Fisher & Hood, 1987). A total of fifty-six participants returned for post-testing. Forty-three participants met our inclusion and exclusion criteria. Post-testing was completed in the same manner as baseline testing and consisted of the CNSVS, SOT, GSC, and SRRS-R.

Data Reduction

Standard scores for CNSVS were calculated by utilizing raw z-scores by age. Standard Scores are computed by the CNSVS software from raw scores normalized to age matched scores relative to other people in a normative sample. CNS Vital Signs standard scores have a mean of 100 and a standard deviation is 15. Higher scores are always better. Domain raw scores for domains were interpreted and calculated as follows: (Gualtieri & Johnson, 2008)

(1) <u>Neurocognitive Index</u>: A mean score of the composite memory, psychomotor speed, reaction time, complex attention, and cognitive flexibility domain scores. This domain provided a general overview of neurocognitive function.

(2) <u>Composite Memory</u>: Verbal and visual memory test scores were summed to give a composite score of a participant's memory.

(3) Verbal Memory: Scores from the verbal memory test were used to interpret a participant's ability to recognize, remember and retrieve words. The domain was calculated by summing correct hits immediate, correct passes immediate, correct hits delay, and correct passes day.

(4) Visual Memory: Scores from the visual memory test were used to interpret a participant's ability recognize, remember and retrieve geometric shapes. The domain was calculated by summing correct hits immediate, correct passes immediate, correct hits delay, and correct passes day.

(5) Processing Speed: Scores from this test were used as a measure of how well one can perform cognitive tasks. Errors were subtracted from correct responses to calculate this domain score.

(6) Executive Function: Scores were used to give a measurement of a participant's mental flexibility, ability to recognize changes in rules and categories, and ability to manage several tasks simultaneously. Incorrect responses were subtracted from correct responses to calculate this domain.

(7) Psychomotor Speed: Scores from both the finger tapping test and symbol digit coding test were summed to produce a measure of how well a participant recognized and processed information. Average taps from the left and right finger-taping test were added to correct symbol digit coding responses to yield this domain score.

(8) Reaction Time: Results from the Stroop test were used to describe a participant's reaction time to both simple and complex sets of directions. Simple and complex reaction times were summed and divided by two to give an overall

average reaction time score.

(9) Complex Attention: A combination of scores from the continuous performance test, shifting attention test, and Stroop test yielded a measure of a participant's ability to both maintain focus and perform tasks quickly and accurately. Specifically, Stroop test commission errors, shifting attention errors, continuous commission errors and continuous performance omission errors were summed to produce this domain score.

(10) Cognitive Flexibility: Scores from the Stroop test and shifting attention test were combined to produce a measure of how well a participant can adapt to quickly changing and increasingly complicated sets of directions. Shifting attention errors and Stroop test commission errors were subtracted from shifting attention correct responses to calculate this domain score.

(11) Reasoning: Scores from the non-verbal reasoning test were utilized to calculate the reasoning domain score. This addressed the ability of a participant to perceive and understand the meaning of abstract visual information. Furthermore, this addressed the ability to recognize the relationship between visual-abstract concepts.

The composite score for the SOT was calculated as follows utilizing the 18 total trials from six different conditions:

(1) Composite Score: A weighted average of equilibrium scores from all 18 trials. Specifically, the following equilibrium scores were averaged to obtain a composite equilibrium score: the condition one average, the condition two average, and the three equilibrium scores from each trial of conditions three

through six. The score was weighted towards the more difficult conditions because balance deficits can be more easily detected in those conditions. Equilibrium scores were calculated as a percentage of the participant's peak sway with a theoretical limit of stability. The limit of stability was calculated using the participant's height and size of base of support. High scores indicated better postural control.

We categorized our symptoms into three separate groups: somatic, cognitive, and neurobehavioral (Table 3.1). These categories were previously described and adapted from Piland et al (Piland et al., 2006). We examined the total symptoms reported for each category and the total symptom severity for each category. For our ten-week post-testing we utilized the same dependent variables for all our measures (SRRS-R, CNSVS, SOT, and GSC). The same testing and data reduction procedures were used on our ten-week post-test data.

Data Analysis

We compared baseline dependent variables between participants in the high, moderate and low psychological distress tertiles to address our first research question (1a-1c). Separate one-way analyses of variance (ANOVA) were performed between the high, moderate and low psychological distress tertiles for all 18 dependent variables. Dependent variables included eleven standard scores of CNSVS, the composite score of the SOT, total symptom severity by category, and total symptoms reported by category. In the event of a significant finding, Tukey's HSD post-hoc testing was performed to identify any significant differences between tertiles. An a priori alpha level of 0.05 was used for all ANOVAs.

We utilized a Chi-Square test of independence to determine the association between changes in psychological distress and changes in our 18 dependent variables following a ten-week adaptation period to address our second research question (2a-2c). Our groups were stratified by whether they showed low, moderate, or high changes in psychological distress level. Change in psychological distress level was calculated by subtracting each participant's baseline SRRS-R score from his or her follow up score. These scores were then ranked in ascending order and divided into low, moderate, and high change tertiles. Change in our dependent variables was defined in a similar fashion as psychological distress level. For each dependent variable, the baseline score was subtracted from the follow up score (change score = re-test score - baseline score). Scores were then ranked in ascending order and dividing into low, moderate, and high change tertiles. An a priori alpha level of 0.05 was used for all chi square analyses. Fisher's exact test was used when 80% of expected cell counts were less than 5.

Table 3.1: Graded Symptom Checklist (GSC) Symptom Categories

Somatic		Cognitive	Neurobehavioral
Headache	Sensitivity to noise	Difficulty concentrating	Trouble falling asleep
Nausea	Ringing in the ear	Feeling "in a fog"	Drowsiness
Vomiting	Sensitivity to light	Difficulty remembering	Fatigue
Dizziness	Blurred vision		Sadness
Poor balance	Neck pain		Irritability

Table 3.2: Statistical Analysis – Research Question One

RQ	Description	Data Source	Comparison	Method
1a	Is there a significant difference in neurocognitive performance, as measured by CNSVS, between participants reporting high, moderate and low levels of psychological distress?	Baseline SRRS-R scores Baseline CNSVS standard scores	CNSVS standard scores between the high, moderate, and low distress groups	11 one-way between-subjects ANOVAs
1b	Is there a significant difference in postural control performance, as measured by the SOT, between participants reporting high, moderate and low levels of psychological distress?	Baseline SRRS-R scores Baseline SOT composite score	SOT composite score between the high, moderate, and low distress groups	1 one-way between-subjects ANOVA
1c	Is there a significant difference in self-reported total symptom severity by category and total symptom severity by category between participants reporting high, moderate and low levels of psychological distress?	Baseline SRRS-R scores Baseline GSC	Total symptom severity by category, and total symptoms reported by category between the high, moderate, and low distress groups	6 one-way between-subjects ANOVAs

Table 3.3: Statistical Analysis – Research Question Two

RQ	Description	Data Source	Comparison	Method
2a	Is a change in psychological distress level associated with a change in neurocognitive performance, as measured by CNSVS, after a ten-week adaptation period?	SRRS-R scores and CNSVS domain scores at baseline and post-test	CNSVS standard scores of high, moderate, and low distress groups as measured by the SRRS-R after baseline and post-test	11 Chi-Square tests of independence
2b	Is a change in psychological distress level associated with a change in postural control performance, as measured by the SOT, after a ten-week adaptation period?	SRRS-R scores and SOT composite score at baseline and post-test	SOT composite score of high, moderate, and low distress groups as measured by the SRRS-R after baseline and post-test	1 Chi-Square test of independence
2c	Is a change in psychological distress level associated with a change in self-reported total symptom severity by category and total symptom severity by category, after a ten-week adaptation period?	SRRS-R scores and GSC at baseline and post-test	Total symptom severity by category, and total symptoms reported by category of high, moderate, and low distress groups as measured by the SRRS-R after baseline and post-test	6 Chi-Square tests of independence

CHAPTER IV

MANUSCRIPT

The Influence of Psychological Distress on Baseline Concussion Measures

Context: Accurate concussion baseline testing helps injury evaluation by allowing post-injury comparisons to pre-injury measures. Baseline measures may be negatively influenced by psychological distress. **Objective:** To determine the influence of psychological distress on baseline concussion measures, and to examine the association between change in psychological distress and change in performance on clinical measures of concussion. **Design:** Prospective cohort study. **Setting:** Clinical research center. **Patients or Other Participants:** Convenience sample of 123 Division I collegiate student-athletes at baseline: 47 females (age = 18.9 ± 4.3 years, height = 164.9 ± 7.8 cm, mass = 60.0 ± 9.9 kg), 76 males (age = 19.4 ± 1.6 years, height = 184.3 ± 8.3 cm, mass = 87.8 ± 14.9 kg). Forty-three athletes returned for follow-up evaluation (26 females, 17 males). **Interventions:** Ten-week adaptation period between baseline and follow-up. **Main Outcome Measure(s):** Dependent variables included the CNS Vital Signs, the Sensory Organization Test (SOT), and symptom reporting on the Graded Symptom Checklist. Psychological distress was assessed using the Social Readjustment Rating Scale-Revised (SRRS-R). **Results:** One way between-subjects ANOVAS revealed that the moderate distress group performed significantly worse than the low distress group on baseline verbal memory domain of the CNS Vital Signs ($F_{2,119} = 3.28$;

P = 0.041). The high distress group reported significantly more symptoms than the low distress group on baseline somatic symptoms reported ($F_{2,119} = 3.61$; *P* = 0.030), and neurobehavioral symptoms reported ($F_{2,119} = 3.13$; *P* = 0.047). Chi-Square analysis revealed that participants with low changes in distress perform better on the SOT ($\chi^2(4)=12.66$; *P* = 0.011). High increases in distress are associated with a moderate increase in somatic symptoms reported ($\chi^2(4)=12.14$, *P* = 0.006). **Conclusions:** Few variables were significantly influenced by distress. Considering the clinical significance of these variables, psychological distress may not be a confounding factor in concussion evaluation. **Key Words:** traumatic brain injury; concussion management; college athlete.

INTRODUCTION

Concussions are best evaluated and managed using a multifaceted approach that includes assessment of neurocognitive function, postural control, symptoms, and a thorough clinical evaluation (McCrory et al., 2009). Accurate baseline testing is useful during post-injury evaluation by allowing comparison to an individualized pre-injury measurement. While 94% of institutions report conducting baseline neurocognitive exams, only 54% of those conducting these exams report checking the accuracy of their results (Covassin et al., 2009). In general, an inaccurate baseline assessment may make it difficult to interpret post-injury assessment data Effort, a previous history of concussion, and learning disabilities can confound neurocognitive assessment (Collins et al., 1999; Green et al., 2001; Hunt et al., 2007). The baseline evaluation process is further complicated because symptoms commonly reported with concussion are not exclusive to only a diagnosis of concussion. Headaches, difficulty concentrating, and nausea may be common even without the presence of a concussion (Piland et al., 2006).

Recently, depression and psychological distress have been introduced as additional confounding factors of baseline evaluation for concussion. Links have been established between depression questionnaire scores and neurocognitive test scores, as well as depressive symptoms and post-concussive symptoms (Garden & Sullivan, 2010; Iverson et al., 2009; Lange et al., 2010). Depression, or a history of depression, is prevalent in a collegiate population, with 14.9% of college students reporting a diagnosis of depression in their lifetime (Gallagher, 2010; Orr & Ketcham, 2009). Depression in college students is theorized to be the result of psychological distress associated with poor adaptation and coping techniques to a new environment. The link between life stress and depression is widely established, with increased levels of psychological distress being shown as a predictor for depressive symptoms (Kelly et al., 2007; Lara et al., 2000; Miller & Chung, 2009). After a period of acclimation to college, psychological distress and depressive symptoms tend to resolve both with and without treatment (Blimling, 1981; Dyson & Renk, 2006; Fisher & Hood, 1987; Kelly et al., 2007; Lapsley et al., 1989; Lara et al., 2000; Miller & Chung, 2009).

In the collegiate setting, concussion baseline testing is typically completed prior to an athlete's season of play, when the student-athlete is likely to experience the greatest amount of psychological distress. It seems possible that completing baseline testing during this transitional time would influence neurocognitive function, postural control, and symptom score. However, there is limited literature available on psychological distress and its interaction with baseline concussion evaluation to support this claim. A recent study limited to collegiate football players and neurocognitive testing did show a relationship between psychological distress and scores at baseline, but did not evaluate any changes over time (Bailey et al., 2010).

Confounding factors such as psychological distress have significant implications on the validity of baseline neurocognitive evaluation. Comparisons back to an invalid baseline that do not accurately represent an athlete's full potential may influence clinicians to make premature, and potentially dangerous, return to play decisions. The purpose of this study was to determine if psychological distress influences neurocognitive function, postural control, and symptom scores at preseason baseline, and to determine if change in psychological distress level is associated with change in performance on clinical measures of concussion after a ten-week adaptation period.

METHODS

Participants

A convenience sample of 165 incoming freshman and transfer student-athletes at a Division I institution completed baseline concussion testing. Participants were excluded if they enrolled in the spring prior to the fall of their freshman year, had a history of concussion within six months of baseline testing, sustained a concussion between baseline and post-testing, or scored less than 10% on the neurocognitive index domain percentile. Of the 165 participants who completed baseline testing, 123 met our inclusion and exclusion criteria (Table 4.1). All participants were part of a larger ongoing clinical concussion management program, and signed an informed consent form approved by our institutional review board.

Instrumentation

Neurocognitive testing was completed using the CNS Vital Signs (CNSVS) (CNS Vital Signs; Chapel Hill, NC). The CNSVS is a computerized neurocognitive assessment that uses a battery of eight widely used and reliable neurocognitive tests to generate eleven clinical domain scores. Using this battery, the CNSVS has been shown to be sensitive to both the severity and degree of recovery of brain injuries and is able to differentiate between healthy subjects and those suffering from a moderate concussion and those suffering from a severe concussion. The CNSVS is well correlated to both conventional and computerized versions of neurocognitive tests. Test-retest reliability and discriminate validity has also been established and is comparable to similar, and more traditional, tests of neurocognition (Gualtieri & Johnson, 2006, 2008). The neurocognitive tests and corresponding clinical domains are presented in Appendix B.

We employed the Sensory Organization Test (SOT) (NeuroCom International Inc.; Clackamas, OR) to evaluate postural stability. The SOT is a computerized measure of postural stability that utilizes two force plates on a moveable surface and a moveable visual surrounding to measure a participant's center of pressure during six varying conditions (Appendix C). The SOT has been previously described in the sports medicine literature, as well as balance research (Guskiewicz et al., 1997; Guskiewicz et al., 2001; Patel et al., 2007). Contributions from the body's three main sensory systems: visual, vestibular, and somatosensory, can be calculated using these six conditions in addition to a composite score. The interaction of these systems and their contribution to overall postural stability may also be assessed. For the purposes of our study, we chose to use only the composite score in our analysis. The sensitivity and specificity of the SOT has been established at 80% and 57% respectively using a 75% confidence interval (Broglio et al., 2008).

Concussion symptoms were assessed using a self-reported graded symptom checklist (GSC). Graded symptom checklists have previously been used as means of quantifying a participant's symptoms following a concussion (Guskiewicz et al., 2003; Lovell & Collins, 1998; McCrea et al., 2003; Patel et al., 2007). Our GSC used an 18-item checklist that examined symptoms common to concussion. Participants ranked each symptom using a seven-point Likert scale from 0 to 6 (0: not experiencing, 1-2: mild, 3-4: moderate, 5-6: severe). During both baseline and post testing, participants were asked to rate their symptoms over the past four weeks. Total symptom severity by category and total symptoms reported by category (Table 3.1) were used in our statistical analysis. Symptom categories were adopted from previous literature examining concussion symptom reporting using the GSC (Patel et al., 2007). Appendix F contains a complete overview of all clinical measures of concussion we utilized.

Psychological distress was quantified using the Revised Social Readjustment Rating Scale (SRRS-R). The SRRS-R is a self reported measure of life-stress that has been used to predict the probability that a participant will develop a variety of illnesses, including depression (Appendix A) (Rahe et al., 1970). Life-stress has been linked throughout the literature to our variable of interest, psychological distress (Mazure, 1998; Monroe et al., 2009). For the purpose of our study, we modified the SRRS-R by removing eight items that healthy college aged athletes are unlikely to experience. These items included: (1) foreclosure on a loan/mortgage, (2) divorce, (3) adult child moving in with parent/ parent moving in with adult child, (4) child develops behavior or learning problem, (5) failure to obtain/qualify for mortgage, (6) child leaving home, (7) obtaining a home mortgage, and (8) retirement. The language of the items were also altered to be more specific to our target population. Finally, our targeted time frame included only the previous four weeks to capture acute psychological distress. Our SRRS-R and overall testing protocol was pilot tested for feasibility of instrumentation on a group of athletes returning for re-baseline testing prior to the start of a non-traditional training season.

Procedures

Participants reported to our clinical research center in groups no larger than six for baseline concussion testing prior to the start of their sport season. Each participant completed a predetermined specific test order that was outlined and recorded in his or her testing folder. This ensured that proper counterbalancing took place among participants. Baseline testing consisted of CNSVS, SOT, GSC, and SRRS-R. The GSC and SRRS-R were built into the CNSVS software and completed in a room with four computers separated by dividers. Distractions were minimized as much as possible by limiting noise. Participants were not allowed to communicate with each other or use their cell phones during testing. A trained technician administered the neurocognitive testing. The SOT was conducted in a separate room and operated by a technician trained in operating the equipment. In total, testing took approximately an hour and fifteen minutes for each participant to complete.

Following baseline testing, participants indicated whether they would be interested in completing additional testing ten weeks following their baseline testing. We chose a 10-week period of time as available literature demonstrated this period of time was needed for individuals to adapt to new social settings (Fisher & Hood, 1987; Lapsley et al., 1989). Due to likely scheduling conflicts with participants, we used a testing window of ten weeks ± 3 days from original baseline. We also attempted to keep the time of day of timing consistent within ± 2 hours of original baseline. Forty-three participants met our criteria for participation in the 10-week follow-up testing. Post-testing was completed in the same manner as baseline testing and consisted of the CNSVS, SOT, GSC, and SRRS-R.

Data Analysis

We categorized our participants into high, moderate, and low psychological distress tertiles to address our primary study purpose. Eighteen separate one-way analyses of variance (ANOVA) were performed between the high, moderate and low psychological distress tertiles for our eighteen dependent variables. Dependent variables included 11 standard scores captured within the CNSVS neurocognitive battery, the SOT composite score, total symptom severity by category, and total symptoms reported by category. In the event of a significant omnibus finding, Tukey's HSD post hoc testing was employed to identify any significant pairwise differences between tertiles. An a priori alpha level of 0.05 was used for all ANOVAs.

We utilized 18 separate 3x3 Chi-Square tests of independence to determine the association between changes in psychological distress and changes for each of our dependent variables following a ten-week adaptation period to address our secondary study purpose. Our groups were stratified by whether they showed low, moderate, or high changes in psychological distress level. Change in psychological distress level was calculated by subtracting each participant's baseline SRRS-R score from his or her follow up SRRS-R score (change score = follow-up score – baseline score). These scores were then ranked in ascending order and divided into low, moderate, and high change tertiles. Change in our dependent variables was defined in a similar fashion as psychological distress level. For each dependent variable, the baseline score was subtracted from the follow up score. Scores were then ranked in ascending order and dividing into low, moderate, and high change tertiles. This method provided us with our low, moderate, and high distress change groups. An a priori alpha level of 0.05 was used for all Chi-Square analyses. Fisher's exact methods were used when less than 80% of expected cell counts were greater than 5.

RESULTS

Baseline Analysis

Participant demographic information for the 123 participants included in our baseline analysis and the 43 participants that returned for the 10-week post-testing session may be found in table 4.1. A one way between-subjects ANOVA revealed a significant omnibus finding between the low, moderate, and high psychological distress groups ($F_{2,120}$ = 277.66; $P < 0.001$). Post hoc analysis revealed significant differences between all three distress groups (Table 4.1). Results observed in our baseline analysis and 10-week follow up evaluations of neurocognitive performance, balance performance, and symptom reporting are detailed below.

Baseline Clinical Evaluation

A significant difference in baseline verbal memory was observed between the psychological distress tertile groups ($F_{2,119}$ = 3.28; $P = 0.041$), such that participants in the moderate psychological distress group (94.56 ± 18.25) performed significantly poorer than participants in the low psychological distress group (104.53 ± 18.51). A significant difference was observed between the psychological distress tertile groups on somatic symptoms reported ($F_{2,119}$ = 3.61; $P = 0.030$), and neurobehavioral symptoms reported ($F_{2,119}$ = 3.13; $P = 0.047$). In both cases, our post hoc analyses identified that participants in the low psychological distress group reported significantly fewer symptoms than participants in the high psychological distress group. Participants in the moderate psychological distress group were not significantly different from the low or high psychological distress groups. There were no significant differences observed on any other CNS Vital Signs standard score, the SOT composite equilibrium score, or any other symptom reporting variables (*P* > 0.05 for all analyses). Table 4.2 contains complete statistical results addressing performance on baseline concussion measures across the low, moderate, and high psychological distress groups.

Ten-Week Follow Up Evaluation

A significant association was found between change in psychological distress level with change in performance on the SOT as measured by the composite equilibrium score ($\chi^2(4)=12.66$; $P = 0.011$), such that any change in psychological distress were associated with low changes in SOT performance. This suggests that the SOT is a stable measure of postural stability that appears unaffected by changes in psychological distress as we have measured it in this study. Furthermore, we observed that moderate change in psychological distress was associated with a high change in total somatic symptoms reported ($\chi^2(4)=12.14$, $P = 0.006$). This implies an increase in psychological distress is associated with an increase in somatic symptoms reported. We did not observe any significant associations between change in psychological distress and change in our remaining clinical measures (*P* > 0.05 for all analyses). Table 4.3 contains the complete statistical results addressing our secondary study purpose.

DISCUSSION

Our findings suggest that psychological distress may not be a confounding variable on an athlete's performance during a preseason baseline concussion assessment. We only observed statistically—but not clinically—significant findings with four of our 18 dependent variables. We observed that participants with a moderate level of psychological distress perform worse on the verbal memory domain of the CNS Vital Signs than participants with low levels of psychological distress. Participants with high levels of distress reported more somatic and neurobehavioral symptoms than participants with low levels of psychological distress. We also observed that an increase in psychological distress was associated with an increase in somatic symptoms reported. Finally, an improvement, or stable levels of psychological distress, was associated with improved or stable postural stability performances.

Our findings raise a few interesting observations. Regarding the verbal memory domain, we expected to find significant differences between the low and high distress groups instead of the low and moderate groups. We observed a ten-point difference between the low and moderate distress groups on verbal memory performance. There is potential that participants in the high psychological distress group cope with distress better than those in the moderate distress group thus resulting in better performances. Also, there may be ideal ranges of distress for performance on this domain. Regardless, a clinical difference of ten points on a single domain of the CNS Vital Signs is likely insufficient to alter the management of an injured athlete. Furthermore, the differences observed in the verbal memory domain were not large enough to cause a significant difference in the composite memory domain.

One must consider the clinical utility of our symptom results despite our statistically significant findings. Although statistically significant, differences of less than one symptom (0.48 vs. 1.22) are clinically meaningless in the context of marked differences between post-injury (mean scores above 20) and pre-injury (mean between 2 to 4) symptom reporting previously reported in the literature (Guskiewicz et al., 2003). Therefore, given our results, it is highly unlikely that psychological distress would influence the return to play decision-making process for a concussed athlete.

Only one other study has examined psychological distress in relation to baseline concussion testing (Bailey et al., 2010). In this study, a small sample of male collegiate football players was utilized and did not examine change over time. Nonetheless, the authors observed a significant relationship between psychological distress and neurocognitive performance; thus, concluding that psychological distress is a confounding factor in concussion evaluation. Our study does not support these findings.

An inherent problem with the study of how psychological distress interacts with sport-related concussion is a lack of accurate and reliable methods to quantify outcome measures of interest. Specific to our study, psychological distress is a very individualized factor that can be difficult to quantify. In general, attempts to quantify most variables of sport psychology, including psychological distress, rely heavily on self-report questionnaires. Validity of self-report questionnaires may be mediocre at best as they rely on subjective participant responses. Furthermore, there is a plethora of scales and measures available with no standard validated measure of a given outcome, especially psychological distress. The discussion of measurement validity is equally volatile with respect to baseline concussion testing, specifically in regards to neurocognitive testing.

Effort, previous history of concussion, and learning disabilities may all affect the validity of neurocognitive testing (Collins et al., 1999; Green et al., 2001; Hunt et al., 2007). More recently, Moser et al. examined the effect of group and individual test settings on baseline neurocognitive performance in high school athletes. The authors found that neurocognitive testing conducted in a group setting may result in poorer performances relative to testing in an individual setting (Moser, Schatz, Neidzwski, & Ott, 2011).

The differences of trait versus state personality should also be considered (Weinberg RS, 2011). The trait approach to personality contends that fundamentals of behavior are relatively stable and consistent regardless of situation. The state approach suggests that behaviors are the result of specific environments, conditions, or situations. Likely, our behaviors and responses to stressors are a combination of the two approaches. Our scale cannot account for these differences between individuals. Some of our participants may have trait personalities that allow them to cope with stressors better than other participants. Although the index score would not reflect individual differences between trait and state personality, these individuals' true behavior and ability to cope with stressors may be drastically different. Additionally, athletes from varying teams may have been experiencing different levels of distress simply due to the timing of their sport season. All participants were baseline tested prior to or at the beginning of the academic year. Football and soccer athletes were preparing for the beginning of their regular season participation while the lacrosse teams were not practicing at all. It is possible the differences in sport season—fall compared to spring—could account for varying levels of psychological distress.

Researchers have previously made recommendations to include additional measures to the baseline assessment in light of significant findings they observed. For example, Bailey et al. (2010) encourage the addition of a psychological distress measure, and Green et al. (2001) suggest measuring motivation/effort. While we did observe statistically significant findings, we acknowledge the limited clinical utility of these findings and further acknowledge the added burden to an already extensive multi-faceted baseline assessment battery encouraged by concussion researchers. This in turn may also decrease the validity of baseline concussion testing and further complicate the logistics associated with conducting large scale baseline concussion testing. Rather than including the entire stress scale, some clinicians may consider screening for only the most commonly reported life stress events we observed in our study (Table 4.4). This would accomplish the goal of screening for psychological distress, eliminate unnecessary items, and serve to maintain a brief baseline protocol.

Given the published shortcomings of baseline concussion testing, some clinical researchers are beginning to wonder if baseline concussion testing is truly worthwhile given the financial, human, and physical resources required to accomplish this task. In some cases, institutions may simply lack these resources to accomplish baseline concussion testing. Recent data suggests that comparing post-injury concussion measures to normative data may be an effective method of identifying neurocognitive and postural control impairments following a concussion (Schmidt JD, In Press). The authors found that comparison of post-concussion neurocognitive, postural control, and symptom severity measures to normative values identified the same impairments as comparison individualized baseline measure. Normative data may be utilized in circumstances where resources are limited for comprehensive baseline evaluation. Given the number of confounding variables (e.g. psychological distress, dehydration, motivation) that have been identified, it is not surprising that clinical research is beginning to establish a case to limit baseline testing only to those athletes with a concussion history or history of attention deficit (and hyperactivity) disorders (Bailey 2007, Bailey 2010, Green 2001, Patel 2006). We recommend that if baseline concussion testing should continue to take place, the process must be rigorously controlled and standardized. Under ideal circumstances, it may be best to re-test athletes following an adaptation period, as we did in this study. However, this would present even greater logistical challenges regarding scheduling, staffing, and equipment availability. As more literature becomes available citing the potential limitations of baseline concussion testing, it may be worthwhile to further consider the merit of comparing post-injury data to normative data rather than baseline data. Also, comparisons to normative data may be the more conservative approach in the return to play decision-making process.

Limitations

Specific to our scale and study design, there are a few potential problems with quantifying psychological distress. For example, being a victim of a crime has a predetermined score. However, neither this item nor its score allows the student-athlete to account for the severity of the crime. Under the constructs of our scale, being the victim of a minor theft will yield the same index score as a victim of a violent crime. Using this same example, our scale does not account for individualized responses to distressful life events. An individual who was the victim of a minor theft 3 weeks ago will likely have a different psychological response than an individual who the victim of a violent crime at the same time. Again, under the constructs of the scale we employed in our study, there would be no difference in index score between these individuals, but there is likely a difference in the true psychological distress experienced between these individuals. Despite these problems, our low, moderate, and high distress groups were statistically different from each other and represented a clinical range for low, moderate and high distress groups that has been previously published (Hobson et al., 1998). An additional limitation to our study involves a relatively small sample size for our post-testing analysis completed ten weeks following preseason baseline. Our follow-up sample also included a different demographic of athletes relative to baseline. For example, we were unable to retest football athletes while we were able to retest all or most athletes from the women's lacrosse, men's soccer, and women's soccer teams. Ultimately this resulted in testing more females than males at follow-up, while at baseline we tested more males than females.

Conclusions

It is important to consider that neurocognitive and postural control testing should serve merely to supplement to the overall management of a patient suffering from a concussion. These measures of concussion should not supersede the clinical judgment derived by the sports medicine team following a comprehensive patient history, observation, and thorough clinical interview; but, rather, simply as an additional tool to assist in monitoring the return to play decision-making process. Our study does not appear to support the clinical utility of including measures of psychological distress as a part of the concussion management paradigm. We acknowledge, however, that a thorough psychological evaluation may be warranted in some unique circumstances.

Table 4.1: Participant Demographic Information by Distress Grouping

Descriptive Factor	Baseline (N = 123)			Follow Up (N = 43)		
	Low	Moderate	High	Low	Moderate	High
Age (years)	19.1 ± .8	19.5 ± 1.9	19.4 ± .9	19.0 ± .3	19.1 ± .5	19.3 ± .7
Height (cm)	179.4 ± 12.0	175.21 ± 12.8	175.3 ± 12.3	168.9 ± 11.3	176.1 ± 8.8	172.4 ± 10.6
Mass (kg)	79.8 ± 17.5	75.6 ± 18.6	75.1 ± 21.5	66.4 ± 14.1	76.5 ± 16.4	67.6 ± 13.1
Male	33	24	19	3	8	6
Female	14	20	13	11	7	8
Sport (Frequency)						
Baseball*	8	2	2	0	0	0
Basketball	3	2	3	0	1	1
Cheerleading	9	10	6	3	1	3
Diving	0	2	0	0	0	1
Football*	5	8	9	0	0	0
Gymnastics	1	0	1	1	0	1
Lacrosse	8	9	0	4	3	4
Soccer	7	2	5	3	4	4
Softball	1	3	1	0	2	0
Track and Field	0	2	2	3	1	0
Wrestling	5	4	3	0	3	0

*For baseball and football- we were unable to recruit subjects for follow up analysis.

Table 4.2: Descriptive Statistical Results for Performance on Clinical Measures of Concussion Across High, Moderate, and Low Psychological Distress Groups

Clinical Measure	Low* Psychological Distress (N=47)		Moderate* Psychological Distress (N=43)		High* Psychological Distress (N=32)		F	*P*
	Mean	SD	Mean	SD	Mean	SD		
CNS Vital Signs								
Neurocognitive Index	102.09	8.927	102.80	8.171	103.12	9.164	0.151	0.860
Composite Memory	105.30	16.201	98.49	10.530	101.34	17.461	1.843	0.163
Verbal Memory	104.53	18.508	94.56	18.251	100.94	19.166	3.278	0.041†
Visual Memory	105.40	13.106	101.82	16.205	101.34	13.047	1.031	0.360
Psychomotor Speed	104.04	19.614	106.32	10.168	105.69	11.286	0.287	0.751
Reaction Time	100.87	12.017	104.11	10.224	98.56	12.523	2.230	0.112
Complex Attention	101.40	17.838	103.39	14.262	107.31	14.652	1.337	0.267
Cognitive Flexibility	98.68	12.876	101.45	12.352	103.28	11.523	1.398	0.251
Processing Speed	100.68	13.985	103.55	15.712	105.34	17.821	0.898	0.410
Executive Functioning	99.02	11.833	102.09	12.033	103.16	11.211	1.378	0.256
Reasoning	99.09	11.833	95.68	13.530	99.09	14.229	0.747	0.476
Sensory Organization Test								
Composite Score	76.79	8.623	75.94	6.962	78.53	6.171	1.105	0.335
Graded Symptom Checklist‡								
Somatic Sx Severity	0.62	1.243	0.70	1.692	1.50	2.615	2.497	0.087
Somatic Sx # Reported	0.48	0.983	0.52	1.151	1.22	1.809	3.607	0.030§
Cognitive Sx Severity	0.45	1.080	0.75	1.527	1.06	2.257	1.405	0.249
Cognitive Sx # Reported	0.32	0.695	0.43	0.759	0.59	1.012	1.094	0.338
Neurobehavioral Sx Severity	0.96	1.628	1.30	1.799	1.63	1.862	1.402	0.250
Neurobehavioral Sx # Reported	0.66	1.069	0.84	1.077	1.31	1.355	3.130	0.047§

* Mean, standard deviation, and range of SRRS-R scores for each group are as follows: Low (12.66 ± 16.34; 0-35), Moderate (97.70 ± 32.82; 43-159), and High (263.59 ± 80.75; 165-497)

† Moderate Psychological Distress Group performed significantly poorer than the Low Psychological Distress Group. No differences were observed between the Moderate and High Distress Groups, and the Low and High Distress Groups.

‡ Sx = Symptom(s)

§High Psychological Distress Group reported significantly higher number of symptoms than the Low Psychological Distress Group. No differences were observed between the High and Moderate Psychological Distress Groups, and the Moderate and Low Psychological Distress Groups.

Table 4.3: Statistical Results for Chi-Square Analyses of Independence Between Change in Psychological Distress and Change in Clinical Measures from Baseline to 10-week Follow Up

Clinical Measure	χ^2	P
CNS Vital Signs		
Neurocognitive Index	3.837	0.459
Composite Memory	1.762	0.827
Verbal Memory	6.382	0.174
Visual Memory	3.428	0.504
Psychomotor Speed	1.573	0.876
Reaction Time	5.025	0.302
Complex Attention	2.097	0.769
Cognitive Flexibility	2.379	0.707
Processing Speed	3.694	0.479
Executive Functioning	2.616	0.643
Reasoning	2.528	0.689
Sensory Organization Test		
Composite Score	12.664	0.011*
Graded Symptom Checklist†		
Somatic Sx Severity	5.902	0.148
Somatic Sx # Reported	12.135	0.006‡
Cognitive Sx Severity	5.389	0.253
Cognitive Sx # Reported	3.636	0.482
Neurobehavioral Sx Severity	2.854	0.608
Neurobehavioral Sx # Reported	3.354	0.534

*There is a significant association between performance change on the SOT and change in psychological distress. Low changes in psychological distress scores are associated with better performances on the SOT.

† Sx = Symptom(s)

‡ There is a significant association between somatic symptoms reported and change in psychological distress level. High increases in psychological distress level are associated with moderately increased number of somatic symptoms reported.

Table 4.4: Abbreviated Rank Ordered Life-Event Means – Commonly Reported Stressors

Item	Weight	BL Fq*	FU Fq‡
Change in residence	35	56 (46%)	4 (9%)
Changing work, sport, or school responsibilities	32	50 (41%)	5 (12%)
Beginning of ceasing formal education	36	28 (22%)	0 (0%)
Changing employers, careers, sport, sport position, or major	41	19 (15%)	6 (14%)
Experiencing financial problems or difficulties	62	14 (11%)	1 (2%)
Changing positions at work or in sport	33	9 (7%)	5 (12%)
Experiencing or being involved in an auto accident	53	9 (7%)	1 (2%)
Being disciplined at work, school, or sport	53	9 (7%)	8 (19%)
Major injury or illness to close family member	72	9 (7%)	3 (7%)

*The number and percentage of participants who reported the item at baseline evaluation.
‡The number and percentage of participants who reported the item at follow up evaluation.

Appendix A: Rank Ordered Life-Event Means - Revised Social Readjustment Rating Scale

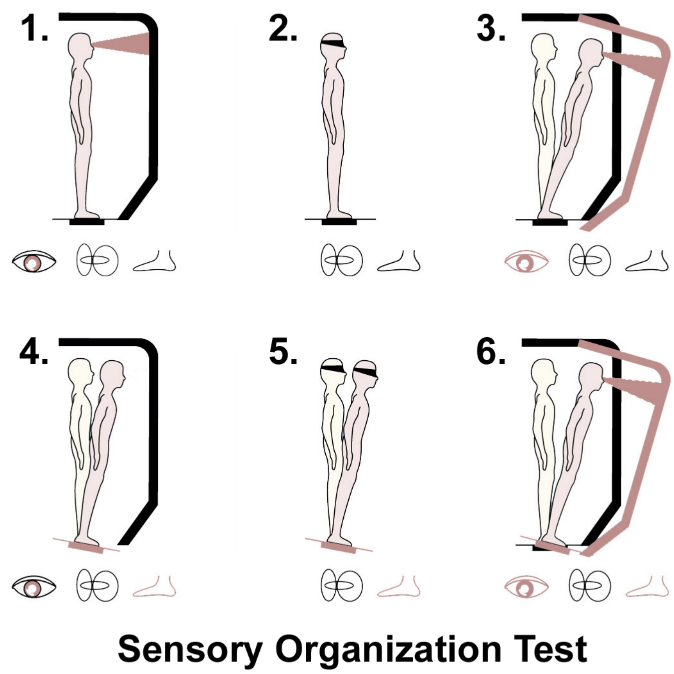
Item	Weight	BL Fq*	FU Fq‡
1. Death of a spouse or mate	87	2 (2%)	1 (2%)
2. Death of a close family member	79	5 (4%)	1 (2%)
3. Major injury or illness to self	78	6 (5%)	4 (9%)
4. Detention in jail or other institution	76	0 (0%)	0 (0%)
5. Major injury or illness to close family member	72	9 (7%)	3 (7%)
6. Being a victim of crime	70	2 (2%)	0 (0%)
7. Being a victim of police brutality	69	0 (0%)	0 (0%)
8. Infidelity	69	2 (2%)	0 (0%)
9. Experiencing domestic violence or sexual abuse	69	0 (0%)	0 (0%)
10. Separation from or reconciliation with spouse or mate	66	4 (3%)	3 (7%)
11. Fired, laid-off, unemployed, cut, or kicked out of work, team, or school	64	0 (0%)	0 (0%)
12. Experiencing financial problems or difficulties	62	14 (11%)	1 (2%)
13. Death of a close friend	61	7 (6%)	4 (9%)
14. Surviving a disaster	59	0 (0%)	0 (0%)
15. Becoming a single parent	59	0 (0%)	0 (0%)
16. Assuming responsibility for sick or elderly loved one	56	2 (2%)	0 (0%)
17. Loss of or major reduction in health insurance or benefits	56	0 (0%)	0 (0%)
18. Self or close family member being arrested for violating the law	56	2 (2%)	1 (2%)
19. Major disagreement over child support, custody, or visitation	53	0 (0%)	1 (2%)
20. Being disciplined at work, school, or sport	53	9 (7%)	8 (19%)
21. Experiencing or being involved in an auto accident	53	9 (7%)	1 (2%)
22. Dealing with unwanted pregnancy	51	0 (0%)	0 (0%)
23. Experiencing unemployment, discrimination, or sexual harassment	48	1 (1%)	0 (0%)
24. Attempting to modify addictive behavior of self	47	3 (2%)	2 (5%)
25. Discovering/attempting to modify addictive behavior- close family member	46	3 (2%)	0 (0%)
26. Employer, team, or school reorganization or downsizing	45	3 (2%)	1 (2%)
27. Dealing with infertility or miscarriage	44	0 (0%)	0 (0%)
28. Getting married, remarried, or engaged	43	0 (0%)	0 (0%)
29. Pregnancy of self, spouse, or mate	43	1 (1%)	0 (0%)
30. Changing employers, careers, sport, sport position, or major	41	19 (15%)	6 (14%)
31. Discrimination or harassment outside of work, school, or sport	39	1 (1%)	0 (0%)
32. Release from jail	39	1 (1%)	0 (0%)
33. Spouse or mate begins or ceases work, sport, or formal education	38	1 (1%)	0 (0%)
34. Major disagreement with boss, coworker, coach, teammate, or professor	37	4 (3%)	0 (0%)
35. Change in residence	35	56 (46%)	4 (9%)
36. Finding appropriate child care or day care	34	1 (1%)	0 (0%)
37. Experiencing a large unexpected monetary gain	33	2 (2%)	0 (0%)
38. Changing positions at work or in sport	33	9 (7%)	5 (12%)
39. Gaining a new family member	33	8 (7%)	1 (2%)
40. Changing work, sport, or school responsibilities	32	50 (41%)	5 (12%)
41. Obtaining a major loan	30	5 (4%)	0 (0%)
42. Beginning or ceasing formal education	26	28 (22%)	1 (2%)
43. Receiving a ticket for violating the law	22	8 (7%)	1 (2%)

*The number and percentage of participants who reported the item at baseline evaluation.
‡The number and percentage of participants who reported the item at follow up evaluation.

Appendix B: CNS Vital Signs Test Modules, Cognitive Domains Evaluated, and Overview of the Test Module

Neurocognitive Test	Cognitive Domain(s)	Overview of Test Module
Verbal Memory Test	Neurocognitive Index Composite Memory Verbal Memory	Participants remember 15 words in a field of 15 distractors. Test is repeated for a measure of delayed memory.
Visual Memory Test	Neurocognitive Index Composite Memory Visual Memory	Participants remember 15 shapes in a field of 15 distractors. Test is repeated for a measure of delayed memory.
Finger Tapping Test	Neurocognitive Index Psychomotor Speed	Participants press the space bar as many times as possible with left and right index finger. Three 10-second trials are completed for each hand.
Symbol Digit Coding	Neurocognitive Index Processing Speed Psychomotor Speed	Participants must correctly match symbols to digits from a key provided. They must make as many correct pairs within two minutes.
Stroop Test	Neurocognitive Index Reaction Time Complex Attention Cognitive Flexibility	Three tests, each with increasingly complex directions. Participants are asked to respond when a word appears as red, blue, green, yellow, then must respond when the font color matches the word, and finally when the font color does not match the word.
Shifting Attention Test	Neurocognitive Index Reaction Time Executive Function Complex Attention Cognitive Flexibility	Participants must match objects either by shape or color, however the rules change throughout the test. For any given rule, the participant must match a shape at the top of the screen to one of two shapes at the bottom of the screen.
Continuous Performance Test	Neurocognitive Index Complex Attention Reaction Time	Participants must press the space bar when the letter "B" appears on the screen among distractor letters. The test lasts five minutes.
Non Verbal Reasoning Test	Neurocognitive Index Reaction Time Reasoning	Participants must identify a missing element or variable that completes a pattern in a presented puzzle.

Appendix C: Sensory Organization Test (SOT) Protocol



Appendix D: Graded Symptom Checklist (GSC) Symptoms

Postconcussion Symptom Scale (PCSS)							
Circle appropriate number for each symptom experienced on a regular basis (> 3 times/wk)							
Symptom	None	Mild		Moderate			Severe
Headache	0	1	2	3	4	5	6
Nausea	0	1	2	3	4	5	6
Vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Poor balance	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Ringing in the ear	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Feeling mentally "foggy"	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Fatigue	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Neck pain	0	1	2	3	4	5	6

Appendix E: Comprehensive Overview of Clinical Measures of Concussion

Variable	Test Module	Overview of Test Module
Neurocognition Neurocognitive Index Composite Memory Verbal Memory Visual Memory Processing Speed Executive Function Psychomotor Speed Reaction Time Complex Attention Cognitive Flexibility Reasoning	CNS Vital Signs (CNSVS)	A computerized neurocognitive assessment that generates eleven clinical domain scores from eight separate neurocognitive tests. Neurocognitive tests include the verbal memory test, visual memory test, finger tapping test, symbol digit coding, stroop test, shifting attention test, continuous performance test, and non-verbal reasoning test. Appendix B contains an overview of the CNS Vital Signs.
Postural Control Composite Score	Sensory Organization Test (SOT)	A computerized assessment of postural stability that utilized measurements of a participant's center of pressure to measure center of gravity sway. Appendix C contains an overview of the SOT.
Symptom Reporting Somatic Symptom Severity Somatic Symptoms # Reported Cognitive Symptom Severity Cognitive Symptoms # Reported Neurobehavioral Symptom Severity Neurobehavioral Symptoms # Reported	Graded Symptom Checklist (GSC)	An 18-item checklist where participants rate symptoms on a 7 point Likert scale ranging from 0-6: 0- not experiencing, 1-2- mild, 3-4- moderate, 5-6- severe. Appendix D is an overview of the GSC while Table 3.1 provides an overview of the GSC symptom clusters.

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